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Study of Land Degradation with Polarimetric SAR and Visible/Near-Infrared Imaging Spectroscopy

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Abstract

The Manix Basin Area of the Mojave Desert has been used extensively for the cultivation of alfalfa with center-pivot sprinkler irrigation systems. Since 1972, a series of these fields has been abandoned. Data were collected using the Airborne Synthetic Aperture Radar and Airborne Visible/Infrared Imaging Spectrometer instruments in the summer of 1990. Polarimetric analysis of the AIRSAR data reveal changes in the morphology of the surfaces of the abandoned fields from cultivation patterns to patterns resulting from wind erosion. Calculation of a normalized difference vegetation index (NDVI) based on the AVIRIS data suggests that the abandoned fields support more vegetation than the undisturbed areas for the first few years of abandonment, but that the vegetation density on fields which have been abandoned for six or more years is lower than the undisturbed desert. Field observations confirm the remote sensing results.

Introduction

Over the last 27 years, many areas of the Manix Lake Basin in the Mojave Desert have been cleared of the natural vegetation and leveled for the purpose of cultivating alfalfa using center pivot irrigation systems. Over the past 20 years a number of fields have been abandoned due to the high cost of electricity needed to pump the irrigation water [1]. This is a significant problem since, "The introduction of sprinkler irrigation systems, especially the center pivot systems, has enabled previously unsuitable rolling sandy lands to be cropped successfully. If and when those soils are abandoned, for reasons of economy or shortage of water, the United States will face an even greater wind erosion threat than it has had to cope with in the past." [2]. The circumstances of similar general cultivation and varying dates of abandonment provide a semi-controlled experiment which allows the examination of changes resulting from the stress of human agricultural activity.

The Manix Lake Basin is located in the Mojave Desert between the Calico Mountains on the west and Afton Canyon on the east along Interstate 15. The center of the study area is located at approximately $35^{\circ}57'$N latitude and $116^{\circ}35'$W longitude. Beginning in the late Pleistocene, at least 350,000 years ago, this region consisted of a series of lakes [3]. The present course of the Mojave River passes through the basin at the southern extreme of the study area. Away from the fields, the native vegetation consists of creosote bush with some smaller desert grasses with approximately 37% plant cover. The soil is a poorly sorted sandy

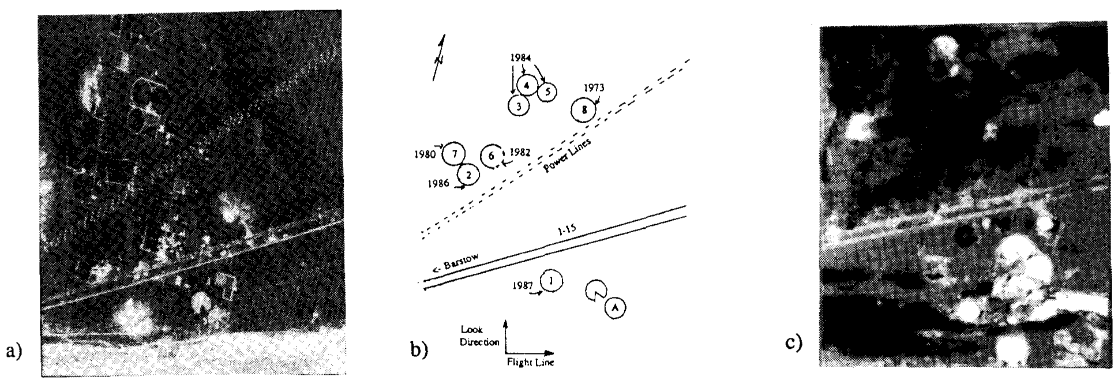

Figure 1. a) L-band total power image of the Manix Basin area. Agricultural fields are visible as circles or ellipses, which are bright if the field is active or dark if it is abandoned. Note the bright diameters visible in fields in the lower half of the image. b) Index map showing flight line, north, field symbols referred to in the text, and year of abandonment for each field. c) Normalized Difference Vegetation Index (NDVI) image generated using Landsat/TM bands synthesized from AVIRIS data. Note the dark plumes extending towards the upper right corner from some of the abandoned fields in the top part of the image.

material with some pebbles, and in some places a poorly developed soil horizon is present.

Data

Data were acquired on June 28, 1990 using the Airborne Synthetic Aperture Radar (AIRSAR) system operated by NASA's Jet Propulsion Laboratory. AIRSAR is a side-looking radar system which operates at three wavelengths: C-Band (5.6 cm), L-Band (24 cm) and P-Band (68 cm). The data acquired by this system records all four complex elements of the Stokes scattering matrix, allowing the mathematical synthesis of the response of the illuminated area for any combination of transmission and reception polarizations [4].

The NASA/JPL Airborne Visible/Infrared Imaging Spectrometer (AVIRIS) instrument was flown over the study area on July 23, 1990. AVIRIS provides data in 224 spectral bands from 0.4 μm to 2.45 μm. These data were calibrated via the empirical line method [5], using field spectrometer data collected on July 24, 1990.

Analysis of AIRSAR Data

Figure 1a (after [1]) is an L-band (24 cm) total power image of the study area. Figure 1b shows a sketch map of the area with the abandoned fields labeled with the date of abandonment and a number. The fields appear as circular or elliptical features which some of which are outlined by bright lines produced by metal fences. The abandoned fields are darker than the background desert, while active fields are slightly brighter and are crossed by bright diameters.

The bright "spokes" can also be seen on abandoned field #1 (abandoned for 3 years and more dimly on abandoned field #2 (4 years). These patterns can be attributed to the circular planting rows [1] and the circular grooves produced by the wheels of the irrigation systems [6]. Their presence suggests that the human-produced circular patterns persist for approximately four years after abandonment.

Figure 2, (after [1]) shows the orientation angle of the maximum co-polarized response from the abandoned fields plotted against the number of years the field had been abandoned. There is a clear trend of departure of the maximum away from 90^{o} (VV polarization). A surface with slight random isotropic roughness would have the greatest co-polarized return at VV polarization [4]. Additionally, the ratio of co-polarized circular polarizations departs further from unity as the fields have lain abandoned for greater lengths of time. The undisturbed desert has the maximum co-polarized return at VV polarization and a circular co-polarization ratio of nearly unity.

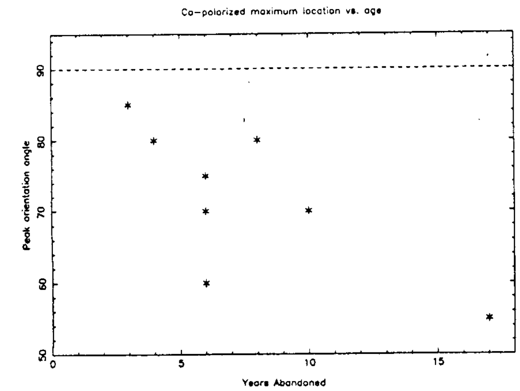

Figure 2. Plot showing the location of the maximum co-polarized response in the AIRSAR data for each of the abandoned fields plotted against the number of years abandoned. The dashed line is the location of the maximum co-polarized response in the undisturbed desert (after [1]).

These polarization effects require anisotropic roughness on the surface being illuminated. Wind ripples formed through processes of wind erosion could provide such anisotropy. A second-order small perturbation model has been used to demonstrate that a nearly sinusoidal topography can yield these polarization effects [1]. Field observations have revealed that wind ripples do occur on the abandoned fields, and that the fields showing the greatest co-polarization shifts are the fields most heavily covered by wind ripples [1].

Analysis of AVIRIS Data

Figure 1c is a Normalized Difference Vegetation Index (NDVI) image calculated using the AVIRIS data. The Landsat Thematic Mapper band passes as reported in [7] were used to weight each AVIRIS band which could be detecting in each TM band. The synthesized TM bands 4 and 3 were used to produce the NDVI image. Figure 3 is a plot of the average NDVI values for each abandoned field plotted as a function of abandonment time. The trend in figure 3 seems to indicate that the vegetation density on an abandoned field is greater for the first three or four years, but there is a rapid decay of vegetation densities on the abandoned fields to values that are significantly less than those of the undisturbed desert. Field observations confirm that the recently abandoned fields are much more heavily vegetated than the old abandoned fields, and that the old abandoned fields are more barren than the surrounding desert. Figure 1c also shows a set of "plumes" of low NDVI values extending downwind (ENE) of the older abandoned fields. These plumes may be the result of sand-blasting of the native desert plants caused by the increased wind erosion from the abandoned fields.

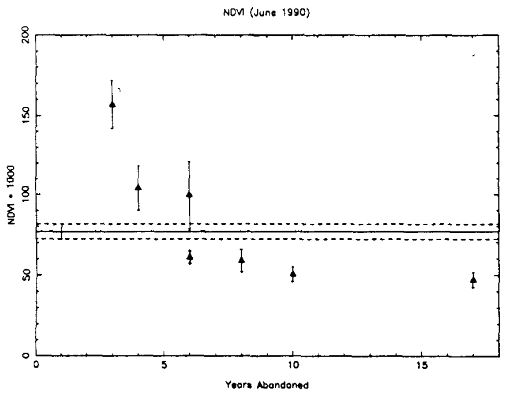

Figure 3. Plot of Normalized Difference Vegetation Index (NDVI) calculated using Landsat/TM bands synthesized from AVIRIS data against number of years abandoned. The variance bars are one standard deviation from the mean for each field. The solid line is the value for undisturbed desert, and the dotted lines are one standard deviation from the mean of the desert.

It is possible to perform spectral unmixing operation on the AVIRIS data and calculate the relative abundances in each pixel of each of a set of defined endmembers. For this study, two endmembers were defined: an average spectrum from field #1, abandoned in 1987, was defined as "recently abandoned field", and an average spectrum of field #8, abandoned in 1973, was defined as "long abandoned field". These were the only endmembers used in this unmixing. Figure 4 shows the abundance of the "recently abandoned field" endmember as a function of time abandoned. The fact that these values lie nearly entirely between 0 and 1000 (1000 indicating 100% relative abundance), suggests that this two endmember linear mixing model is well suited to describing the spectral characteristics of the abandoned fields.

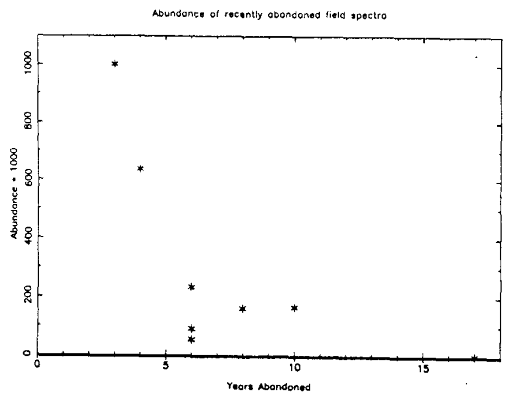

Figure 4. Plot of abundance of "recently abandoned field" endmember against number of years of abandonment for all abandoned fields.

Conclusions and Future Work

This study demonstrates that both radar and imaging spectroscopy can be useful in investigating human-induced land degradation. Polarimetric SAR is capable of detecting the presence of certain kinds of features below the pixel resolution level if such features cover a sufficiently large area. Both data sets and field observations seem to show that the abandoned fields are not returning to their original pre-disturbance state on timescales of a few decades.

In addition to the AIRSAR and AVIRIS data, several other datasets are being analyzed. Two Landsat TM images, one from 1984 and one from 1985, along with a sequence of Landsat MSS images stretching from 1973 through 1988 will be used to look at changes in NDVI and spectral signatures of the abandoned fields. Data has also been acquired over this area using the Russian RESOURCE satellite system, which provides three bands of data in the visible and near-infrared (0.5-0.6 μm, 0.6-0.7 μm, and 0.8-0.9 μm) at a pixel resolution of 30 meters. An NDVI calculated from the RESOURCE data shows the same general pattern as that based on the AVIRIS data although the RESOURCE data seems to be somewhat noisy.

Supplementing and extending the remote sensing observations have been several trips to the field area to observe the state of the abandoned fields and the surrounding desert from the ground. The field observations have included: Sampling of the ecological communities present in the surrounding desert and on the abandoned fields, collection of soil samples for laboratory analysis, and *in situ* measurements of soil properties. These field observations will be used as ground truth for the remotely sensed data and also to further understand the processes acting on the abandoned fields.

Plans are being made to extend this study to include other regions where agriculture is being performed in marginal arid to semi-arid environments. One area being looked at as a potential target area is the Sandhills region of NE Colorado and Nebraska. The ultimate focus of this project is to develop an understanding of land degradation which would enable monitoring with remote sensing techniques on regional and global scales.

References

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